Technology of Industrial Temperature Sensors

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This section describes the technology of the five primary industrial temperature sensors, all of which are included in this study:

- Thermocouples
- Resistance Temperature Detectors (RTDs)
- Thermistors
- Infrared thermometers
- Fiber optic temperature sensors

Thermocouple Technology

A thermocouple is composed of two wires composed of dissimilar metals that are joined together at one end. At this end, which is where the conductors are exposed to the process temperature, is the measurement junction. At the other end of the conductors a reference, or cold, junction is formed. This reference junction is normally formed where the conductor is attached to the measurement device.

Measuring Junction

The measuring junction is the point where two metal wires come together. These wires are usually either soldered or welded together, forming a junction. There are three types of thermocouple measuring junctions:

- Exposed junction
- Grounded junction
- Ungrounded junction

Exposed Junction. An exposed junction has no protective assembly or tube covering the junction. Exposed junctions have the fastest response time, the lowest radiation error, and the least conduction error. Disadvantages are susceptibility to corrosion and fragility. Exposed junction thermocouples are also prone to pick up stray electromagnetic signals unless this is guarded against.

Grounded Junction. A grounded junction is similar to an exposed junction, except that a protective metallic sheath encloses the elements and insulation. In a grounded junction, the thermocouple wires are welded directly to the surrounding sheath material, forming a completely sealed junction. A grounded junction is more rugged and capable of tolerating physical and mechanical abuse. It is also more resistant to corrosion and oxidation. A disadvantage of the grounded junction is slower response time. Grounded junction thermocouples are also more susceptible to conduction error and radiation error than are exposed junction thermocouples. Like exposed junction thermocouples, they are prone to pick up stray electromagnetic signals.

Ungrounded Junction. An ungrounded junction is like a grounded junction except that the junction of the thermocouple wires is not electrically connected to the metallic sheath. An electrical insulator separates the junction from the tip of the closed-end sheath. Like the grounded junction, an ungrounded junction is more rugged and tolerant of abuse. It is also shielded from electromagnetic interference. Its disadvantages are slow response time, susceptibility to conduction errors, and susceptibility to radiation errors.

Measuring the Reference Junction

When the measuring junction and the reference junction have different temperatures, a continuous current flows through the circuit. It continues to flow as long as there is a difference in temperature between the two junctions. Thomas Seebeck discovered this phenomenon in 1821, and it is called the Seebeck effect. The resulting voltage is called the Seebeck voltage. This voltage is a function of the difference in temperature between the measuring junction and the reference junction. It is nonlinear with respect to temperature, although it is approximately linear for small changes in temperature.

Measuring the Seebeck voltage directly with a voltmeter at the reference junction does not give an accurate result because the connection between the thermocouple wires and the voltmeter leads creates a new thermoelectric circuit. Since the voltage read by the voltmeter is proportional to the difference in temperature between the measuring junction and the reference junction, it is necessary to know the temperature at the reference junction to determine the temperature of the measuring junction. This output is in the form of millivolts or microvolts.

There are several methods used to take into account the temperature of the reference junction in determining the measuring junction temperature:

- Creating an ice bath
- Hardware compensation
- Software compensation

Ice Bath. Using the ice bath method, a junction is created within the circuit and inserted into an ice bath. This junction now becomes the reference junction, and it is at the temperature of 32^{o} F. By adding the known voltage from the reference junction to the voltage from the measuring junction, it is possible to calculate the temperature at the measuring junction. The term “cold-junction compensation” comes from this practice of creating a reference junction in an ice bath.

A second method is through hardware compensation. A variable voltage source is inserted into the thermoelectric circuit. This voltage source generates a compensating voltage in accordance with the ambient temperature, adding a correct voltage that cancels unwanted thermoelectric signals. Canceling these unwanted signals leaves only the voltage from the measuring junction.

Hardware Compensation. Hardware compensation has the advantage that it is not necessary to actually measure the ambient temperature at the reference junction. A disadvantage of this method is that it is necessary to have a separate compensation circuit for each type of thermocouple. The circuitry used in hardware compensation also adds some error in the temperature measurement.

Software Compensation. In software compensation, the temperature at the reference junction is measured with a temperature sensor. Usually either a thermistor or an integrated circuit sensor are used. Once the temperature of the reference junction is known, software is used to calculate the temperature at the measuring junction. This is possible because tables are built into software programs that correlate specific temperatures with voltage values for different thermocouple types.

Thermocouple Types

Thermocouples are made up of two dissimilar metals, and they are classified according to the type of metal used to make them up. Industry specifications recognize a number of types of thermocouples, which have been given alphabetical letter designations. Different thermocouple types have different temperature ranges. However, these ranges are not absolute, since wire thickness affects temperature range. Figure 3-1 gives different types of thermocouples along with their metal composition and their temperature ranges.

Figure 3-1
Thermocouple Types

T/C Type	Metal Composition	Temperature Range	Comments
J	Iron/Copper-Nickel	32 °F to 1382°F	Not recommended for low temperatures; Oxidizes rapidly due to iron
K	Nickel-Chromium/Nickel-Aluminum	-328 °F to 2282 °F	Most commonly used type; Wide temperature range
E	Nickel-Chromium/Copper-Nickel	-328 °F to 1652 °F	Highest EMF change per degree
T	Copper/Copper-Nickel	-328 °F to 662 °F	Performs well with moisture present; Used for low temperature and cryogenic applications
S	Platinum-10% Rhodium/Platinum	32 °F to 2642 °F	Used for very high temperatures; Subject to contamination; More expensive due to noble metals
R	Platinum-13%Rhodium	32 °F to 2642 °F	Used for very high temperatures; Subject to contamination; More expensive due to noble metals
B	Platinum-30% Rhodium/Platinum-6% Rhodium	32 °F to 3092 °F	Subject to contamination; Used for very high temperatures; Used in the glass industry
N	Nickel-14.2% Chromium-1.4% Silicon/Nickel-4.4% Silicon-0.1% Magnesium	-450 °F to 2372 °F	An alternative to type K. More stable at high temperatures

Classification of Thermocouples by Type

In this study, thermocouples are classified according to the following types:

- Type J
- Type K
- Type T
- Type E
- Other Types

RTD Technology

The history of RTD technology goes back to Sir William Siemens. About 50 years after Seebeck's discovery concerning thermoelectricity, Sir William Siemens discovered that there is a relation between temperature change and the resistivity of metals. In making this discovery, Siemens relied on research done by Sir Humphrey Davy. Siemens established the use of platinum as the element of an RTD. Platinum RTDs make use of the fact that the electrical resistance of certain metals increase or decrease as temperature increases or decreases.

The basic principle of an RTD is that, as temperature increases or decreases, the electrical resistance of certain metals increases or decreases in a predictable and repeatable manner. The most commonly used metals are platinum, copper, and nickel. There are several reasons why these metals are used. One reason is that these metals react in a very predictable way as temperature changes. Even though these metals do not react in a completely linear manner with temperature change, they are substantially more linear than thermocouples. Secondly, these metals are available in nearly pure form. Third, these metals can all be processed into very fine wire. This is especially important when manufacturing wirewound RTDs.

Classification of RTDs by Type

In this study, RTDs are classified into the following two types:

- Wirewound
- Thin Film

Thermistor Technology

The thermistor is another resistance-based temperature sensor. The term 'thermistor' is derived from the phrase "thermally sensitive resistor." Unlike many RTDs, however, thermistors have a negative temperature coefficient. As temperature increases, the resistance of a thermistor decreases. However, the amount of change in resistance per degree is much greater in a thermistor than in an RTD. This makes a thermistor a much more sensitive device than an RTD. However, the resistance change in a thermistor is very non-linear. As a result, thermistors are normally used only over a very small temperature span.

Thermistors are not as widely used as RTDs, and they are not very widely used in industrial applications. There are several reasons for this. One is that they have a limited span. Secondly, they are subject to permanent decalibration if exposed to high temperatures. Third, they are quite fragile and should not be exposed to vibration or shock. Despite their lack of popularity in industrial applications, thermistors have achieved wide use in the food transportation and service industry.

Infrared Technology

Infrared sensing is usually done by means of an infrared thermometer. An infrared thermometer detects the infrared energy emitted by materials at temperatures above absolute zero, and uses this value to measure temperature. One basic design includes a lens that focuses infrared (IR) energy onto a detector. This energy is then converted to an electrical signal that can be displayed in temperature units. Ambient temperature variations must be compensated for to give an accurate reading. Using this arrangement, it is possible to determine the temperature of an object without making physical contact with the object being measured.

The ability to make non-contact temperature measurement of objects makes infrared technology well suited for measuring temperature in situations where probe-type sensors do not produce accurate results. Examples include moving objects, objects in a vacuum, objects in an electromagnetic field, or in applications requiring a fast response.

While designs for IR thermometers have been around since the 19th century, the technology to create practical measuring instruments from these designs was not available until the 1930s. Since that time, many advances have been made in the use of infrared thermometers, and they have gained wide usage in research and industry.

This study includes both fixed and portable thermometers, as well as linescanners. Linescanners are fixed units, and are classified as fixed thermometers in this study. This study does not include infrared cameras, or thermal imaging technology. Infrared cameras are very high-end infrared products, many of which sell in the $20,000 to $100,000 range. These products incorporate many features that make them unlike other temperature sensors, and are not included in this study.

The following sections describe the three types of infrared products that are included in this study:

- Infrared thermocouples
- Portable (point-and-shoot) and fixed (online) infrared thermometers
- Infrared linescanners

Infrared Thermocouples

Infrared thermocouples, despite their name, are not actually thermocouples. Instead, they are a type of thermometer that contains an infrared detector. The output from infrared thermocouples emulates the output from particular thermocouple types. If someone wishes to replace a type K thermocouple with a noncontact form of measurement, an infrared thermocouple is available for that thermocouple type. By emulating the output from a particular thermocouple type, infrared thermocouples can replace thermocouples and provide the input that a loop controller, programmable logic controller (PLC), transmitter, or recorder is expecting. Different infrared thermocouple models are designed to match particular temperature requirements. Exergen (Watertown, MA) was among the first companies to receive a patent on infrared thermocouples, in 1992.

Many infrared thermocouples contain a sensing detector called a thermopile. A thermopile is an array of thermocouple junctions that are connected together. The thermopile contains a black material that absorbs infrared radiation. Temperature increases in proportion to the amount of infrared radiation absorbed, and the thermocouple junctions produce a corresponding voltage output. Dexter Research Center (Dexter, Michigan) is a major supplier of infrared sensing thermopile detectors. Dexter's thermopiles are hermetically sealed in an atmosphere of inert gas.

Infrared Thermometers

An infrared thermometer detects the infrared energy emitted by materials at temperatures above absolute zero, and uses this value to measure temperature. One basic design includes a lens that focuses infrared energy onto an infrared detector. This energy is then converted to an electrical signal that can be displayed in temperature units. Ambient temperature variations must be compensated for to give an accurate reading. Using this arrangement, it is possible to determine the temperature of an object without making physical contact with the object being measured.

Infrared thermometers are available in both portable and fixed models. Portable models use a point-and-shoot method. If you point the thermometer at the material or object whose temperature you want to measure, you can read the temperature of the object on the thermometer display. Some models are available with circular laser sighting. This shows the actual area whose temperature is being measured with a red circular display. Portable models can be used to measure the temperature of many different devices. Examples of applications include measuring the temperature of electrical circuits, automobile engines, tires, concrete, steam traps, furnaces, food transportation, heat-treating, and plastics.

Fixed infrared thermometers are also called online thermometers. Online thermometers are used to measure the temperature of materials in a fixed location, such as a process control loop. Fixed thermometers are available in a variety of body formats, operating wavelengths, and output signals. Materials that are extremely hot, moving, or inaccessible are ideal candidates for online systems.

Infrared Linescanners

Infrared linescanners contain an infrared thermometer, a rotating mirror, and accompanying electronics. As the mirror scans across the product's surface, the thermometer can take a large number of individual temperature measurements. If the product is moving, two-dimensional data can be obtained. Output from the linescanner is transmitted to a personal computer, and a thermal map of the surface of the product is displayed on the computer monitor. Linescanners are used in the manufacturing of flat glass, glass windshields, and in metals manufacturing.

Classification of Infrared Temperature Sensors

In this study, infrared temperature sensors are classified as follows:

- Portable infrared thermometers
- Fixed infrared thermometers

Portable infrared thermometers include portable infrared thermocouples and point-and-shoot infrared thermometers. Fixed infrared thermometers include fixed infrared thermocouples, online infrared thermometers, and linescanners.

Fiber Optic Temperature Sensors

Fiber optic temperature sensors are a noncontact form of temperature measurement that uses optical fibers in making temperature measurements. Most types of fiber optic temperature sensors work by placing a temperature-sensing component on one tip of the optical fiber. The other end is attached to a measuring system that collects radiation and processes it into a temperature value.

Luxtron claims to be the first company to commercialize fiber optic temperature sensor technology. Luxtron was founded in 1978, and today is the leading supplier of fiber optic temperature sensors. Luxtron calls its pioneering temperature sensing method Fluoroptic® Thermometry. Other technologies employed by Luxtron include Radiation Thermometry and Optical Thin Film Monitoring.